

5 PREPARATION OF  $\epsilon$ -PHASE SILVER VANADIUM OXIDE  
FROM  $\gamma$ -PHASE SVO STARTING MATERIAL

CROSS REFERENCE TO RELATED APPLICATION

10 This application claims priority based on  
provisional application Serial No. 60/254,918, filed  
December 12, 2000.

BACKGROUND OF THE INVENTION

15 1. FIELD OF THE INVENTION

This invention relates to the conversion of  
chemical energy to electrical energy. More  
particularly, this invention relates to the preparation  
of an improved cathode active material for non-aqueous  
20 lithium electrochemical cells, and still more  
particularly, a cathode active  $\epsilon$ -phase silver vanadium  
oxide (SVO,  $\text{Ag}_2\text{V}_4\text{O}_{11}$ ) prepared using a  $\gamma$ -phase silver  
vanadium oxide ( $\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1}$ ) starting material. The  
product cathode active material can be used in an  
25 implantable electrochemical cell, for example of the  
type powering a cardiac defibrillator, where the cell  
may run under a light load for significant periods  
interrupted from time to time by high rate pulse  
discharges.

30 The reaction of  $\gamma$ -phase SVO with a source of silver  
produces  $\epsilon$ -phase SVO that possesses a lower surface area  
than SVO produced from other vanadium-containing  
starting materials. The relatively low surface area of  
this new  $\epsilon$ -phase SVO material results in greater long  
35 term stability for the cathode active material in

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5 comparison to other forms of SVO with higher specific  
surfaces areas.

## 2. PRIOR ART

10 The prior art discloses many processes for  
manufacturing SVO; however, they result in a product  
with greater surface area than the material prepared by  
the current invention.

Specifically, U.S. Patent No. 4,391,729 to Liang et  
al. discloses the preparation of silver vanadium oxide  
15 by a thermal decomposition reaction of silver nitrate  
with vanadium oxide conducted under an air atmosphere.  
This decomposition reaction is further detailed in the  
publication: Leising, R.A.; Takeuchi, E.S. *Chem. Mater.*  
1993, 5, 738-742, where the synthesis of SVO from silver  
20 nitrate and vanadium oxide under an air atmosphere is  
presented as a function of temperature. In another  
reference: Leising, R.A.; Takeuchi, E.S. *Chem. Mater.*  
1994, 6, 489-495, the synthesis of SVO from different  
silver precursor materials (silver nitrate, silver  
25 nitrite, silver oxide, silver vanadate, and silver  
carbonate) is described. The product active materials  
of this latter publication are consistent with the  
formation of a mixture of SVO phases prepared under  
argon, which is not solely  $\epsilon$ -phase  $\text{Ag}_2\text{V}_4\text{O}_{11}$ .

30 Also, the preparation of SVO from silver oxide and  
vanadium oxide is well documented in the literature. In  
the publications: Fleury, P.; Kohlmuller, R.C.R. *Acad.*  
*Sci. Paris* 1966, 262C, 475-477, and Casalot, A.;  
Pouchard, M. *Bull Soc. Chim. Fr.* 1967, 3817-3820, the  
35 reaction of silver oxide with vanadium oxide is

5 described. Wenda, E. J. *Thermal Anal.* 1985, 30, 89-887,  
present the phase diagram of the  $V_2O_5$ - $Ag_2O$  system in  
which the starting materials are heated under oxygen to  
form SVO, among other materials. Thus, Fleury and  
Kohlmuller teach that the heat treatment of starting  
10 materials under a non-oxidizing atmosphere (such as  
argon) results in the formation of SVO with a reduced  
silver content.

In U.S. Patent No. 5,955,218 to Crespi et al., the  
process of heat-treating SVO prepared by a thermal  
15 decomposition reaction to improve the electrochemical  
performance of the material is disclosed. In this  
patent, thermal decomposition SVO prepared according to  
U.S. Patent Nos. 4,310,609 and 4,391,729, both to Liang  
et al., under an air atmosphere at a somewhat lower  
20 temperature of 360°C is described. However, the '218  
patent to Crespi et al. demonstrates that adding a  
second heat treatment step increases the crystallinity  
of the resulting active material. The present invention  
is concerned with the product active material's surface  
25 area, and not necessarily its crystallinity.

U.S. Patent No. 5,221,453 to Crespi teaches a  
method for making an electrochemical cell containing  
SVO, in which the cathode active material is prepared by  
a chemical addition reaction of an admixed 2:1 mole  
30 ratio of  $AgVO_3$  and  $V_2O_5$  heated in the range of 300°C. to  
700°C. for a period of 5 to 24 hours. Crespi does not  
discuss  $\gamma$ -phase SVO in the context of this invention.  
Therefore, the  $\epsilon$ -phase material described by the current  
invention could not be manufactured by this process.

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5 U.S. Patent Nos. 6,130,005 and 5,955,218, both to  
Crespi et al., relate to heat treated silver vanadium  
oxide materials, for example,  $\gamma$ -phase SVO heat treated  
to form decomposition-produced SVO (dSVO). The starting  
material does not appear to be heated for further  
10 combination with a source of silver or other metal.  
Also, U.S. Patent No. 5,895,733 to Crespi et al. shows a  
method for synthesizing SVO by using AgO and a vanadium  
oxide as starting materials. However, the result is not  
a low surface area  $\epsilon$ -phase SVO cathode material, as  
15 disclosed in the current invention.

U.S. Patent No. 5,545,497 to Takeuchi et al.  
teaches cathode materials having the general formula of  
 $\text{Ag}_x\text{V}_2\text{O}_y$ . Suitable materials comprise a  $\beta$ -phase SVO  
having in the general formula  $x = 0.35$  and  $y = 5.18$  and  
20 a  $\gamma$ -phase SVO having  $x = 0.74$  and  $y = 5.37$ , or a mixture  
of the phases thereof. Such SVO materials are produced  
by the thermal decomposition of a silver salt in the  
presence of vanadium pentoxide. In addition, U.S.  
Patent No. 6,171,729 to Gan et al. shows exemplary  
25 alkali metal/solid cathode electrochemical cells in  
which the cathode may be an SVO of  $\beta$ -,  $\gamma$ - or  $\epsilon$ -phase  
materials. However, none of Gan et al.'s methods are  
capable of producing a low surface area  $\epsilon$ -phase cathode  
material, as per the current invention.

30 Therefore, based on the prior art, there is a need  
to develop a process for the synthesis of mixed metal  
oxides, including silver vanadium oxide, having a  
relatively low surface area. An example is a low  
surface area SVO prepared using a silver-containing  
35 compound and  $\gamma$ -phase SVO as starting materials. The

5 product  $\epsilon$ -phase SVO is a cathode active material useful for non-aqueous electrochemical cells having enhanced characteristics, including the high pulse capability necessary for use with cardiac defibrillators.

10 SUMMARY OF THE INVENTION

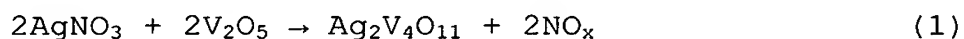
The current invention relates to the preparation of an improved cathode active material for non-aqueous lithium electrochemical cells, and in particular, a cathode active material that contains  $\epsilon$ -phase SVO prepared using a  $\gamma$ -phase SVO starting material. The reaction of  $\gamma$ -phase SVO with a source of silver produces  $\epsilon$ -phase SVO possessing a lower surface area than  $\epsilon$ -phase SVO produced from other vanadium-containing starting materials. The present synthesis technique is not, however, limited to silver salts since salts of copper, magnesium and manganese can be used to produce relatively low surface area metal oxide active materials as well. The relatively low surface area of the  $\epsilon$ -phase SVO material provides an advantage in greater long term stability when used as an active cathode material compared to SVO with a higher specific surface area.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

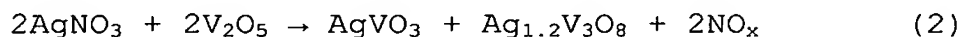
The current invention discloses that reacting a  $\gamma$ -phase SVO material with a source of silver, or other suitable metal salt, produces pure  $\epsilon$ -phase SVO ( $\text{Ag}_2\text{V}_4\text{O}_{11}$ ). This product material possesses a relatively lower surface areas in comparison to active materials synthesized by a thermal decomposition reaction under an

5 oxidizing atmosphere. Decreased surface area is an unexpected result.

The thermal reaction of silver nitrate with vanadium oxide under an air atmosphere is a typical example of the preparation of silver vanadium oxide by a decomposition reaction. This reaction is set forth below in Equation 1:

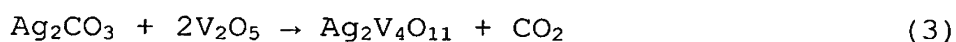


15 The physical characteristics of SVO material (i.e. particle morphology, surface area, crystallinity, etc.) produced by this reaction are dependent on the temperature and time of reaction. In addition, the reaction environment has a dramatic effect on the product material. The same reaction of silver nitrate with vanadium oxide conducted under an argon atmosphere is depicted below in Equation 2:



25 Thus, the synthesis of SVO under an inert atmosphere results in the formation of a mixture of silver vanadate ( $\text{AgVO}_3$ ) and  $\gamma$ -phase SVO ( $\text{Ag}_{1.2}\text{V}_3\text{O}_8$ ). This is described in the above-referenced publication by Leising, R.A.; Takeuchi, E.S. *Chem. Mater.* 1994, 6, 489-495. As reported by Leising et al., a mixture of material phases is less suitable than a single  $\epsilon$ -phase SVO ( $\text{Ag}_2\text{V}_4\text{O}_{11}$ ) as a cathode active material for lithium electrochemical cells. For this reason, argon is typically not preferred for synthesis of SVO cathode active material.

5 A more benign preparation technique for  $\epsilon$ -phase SVO  
 from vanadium oxide and silver carbonate ( $\text{Ag}_2\text{CO}_3$ )  
 according to Equation 3 below results in the release of  
 $\text{CO}_2$  gas, which is a nontoxic byproduct. However, the  
 specific surface area of the product SVO is also higher  
 10 than the surface area of SVO prepared from silver  
 nitrate. This is shown below in Table 1.



15 Thus, a synthesis technique for SVO using vanadium  
 oxide and either silver oxide or silver carbonate, or  
 other preferred metal salts, while eliminating the  
 formation of toxic  $\text{NO}_x$  byproduct, results in an SVO  
 material with a higher specific surface area than SVO  
 20 produced from vanadium oxide and silver nitrate.

Table 1  
 Specific Surface Area of  $\epsilon$ -Phase SVO

<u>Starting Materials</u>	<u>Synthesis Temperature</u>	<u>BET Surface Area</u>
$\text{V}_2\text{O}_5 + \text{AgNO}_3$	500°C.	0.42 m <sup>2</sup> /g
$\text{V}_2\text{O}_5 + 0.5\text{Ag}_2\text{O}$	500°C.	0.64 m <sup>2</sup> /g
$\text{V}_2\text{O}_5 + 0.5\text{Ag}_2\text{CO}_3$	500°C.	0.81 m <sup>2</sup> /g
$\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1} + 0.15\text{Ag}_2\text{O}$	500°C.	0.54 m <sup>2</sup> /g
$\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1} + 0.15\text{Ag}_2\text{CO}_3$	500°C.	0.44 m <sup>2</sup> /g

25 The present invention is an alternate preparation  
 synthesis that does not produce noxious by-products,  
 such as  $\text{NO}_x$  and, additionally, results in an active

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5 material with a desirable relatively low surface area.  
Benefits attributed to the present synthesis process for  
the formation of a cathode active material are  
illustrated in the following examples:

10 Example 1

In contrast to the prior art syntheses described  
above, SVO of the present invention is prepared using  
 $\gamma$ -phase SVO ( $\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1}$ ) as a starting material instead of  
 $\text{V}_2\text{O}_5$ . In particular, a 12.90 gram sample of  $\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1}$   
15 was combined with a 1.09 gram sample of  $\text{Ag}_2\text{O}$ , and heated  
to  $500^\circ\text{C}$ . under a flowing air atmosphere for about 16  
hours. The sample was then cooled, mixed and reheated  
under a flowing air atmosphere at about  $500^\circ\text{C}$ . for about  
24 hours. At this point, the material was cooled and  
20 analyzed by x-ray powder diffraction and BET surface  
area measurements. The x-ray powder diffraction data  
confirmed the formation of  $\epsilon$ -phase SVO ( $\text{Ag}_2\text{V}_4\text{O}_{11}$ ). The  
material displayed a BET surface area of  $0.54 \text{ m}^2/\text{g}$ .

25 Comparative Example 1

As a comparison, SVO was prepared by a prior art  
combination reaction. In particular, a 9.00 gram sample  
of  $\text{V}_2\text{O}_5$  was combined with a 5.73 gram sample of  $\text{Ag}_2\text{O}$ , and  
30 heated to about  $500^\circ\text{C}$ . under a flowing air atmosphere  
for about 16 hours. The sample was then cooled, mixed  
and reheated under a flowing air atmosphere at about  
 $500^\circ\text{C}$ . for about 24 hours. At this point the material  
was cooled and analyzed by x-ray powder diffraction and  
35 BET surface area measurements. The material displayed a  
BET surface area of  $0.64 \text{ m}^2/\text{g}$ , which is significantly



5 higher than the specific surface area of the material prepared in Example 1.

#### Example 2

10  $\epsilon$ -phase SVO according to the present invention was also prepared using a  $\gamma$ -phase SVO starting material in combination with silver carbonate. In particular, a 5.00 gram sample of  $\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1}$  was combined with a 0.50 gram sample of  $\text{Ag}_2\text{CO}_3$ , and heated to about  $500^\circ\text{C}$ . under a  
15 flowing air atmosphere for about 16 hours. The sample was then cooled, mixed and reheated under a flowing air atmosphere at about  $500^\circ\text{C}$ . for about 24 hours. At this point, the material was cooled and analyzed by x-ray powder diffraction and BET surface area measurements.  
20 The x-ray powder diffraction data confirmed the formation of  $\epsilon$ -phase SVO ( $\text{Ag}_2\text{V}_4\text{O}_{11}$ ), while the material displayed a BET surface area of  $0.44 \text{ m}^2/\text{g}$ .

#### Comparative Example 2

25 As a comparison to Example 2, SVO was prepared using  $\text{V}_2\text{O}_5$  and  $\text{Ag}_2\text{CO}_3$ . In particular, a 15.00 gram sample of  $\text{V}_2\text{O}_5$  was combined with a 11.37 gram sample of  $\text{Ag}_2\text{CO}_3$ , and heated to about  $450^\circ\text{C}$ . under a flowing air  
30 atmosphere for about 16 hours. The sample was then cooled, mixed and reheated under a flowing air atmosphere at about  $500^\circ\text{C}$ . for about 24 hours. At this point the material was cooled and analyzed by x-ray powder diffraction and BET surface area measurements.  
35 The material displayed a BET surface area of  $0.81 \text{ m}^2/\text{g}$ , which is nearly twice the specific surface area of the material prepared in Example 2.

5

## Example 3

Copper silver vanadium oxide or CSV0  
( $\text{Cu}_{0.2}\text{Ag}_{0.8}\text{V}_2\text{O}_{5.6}$ ) was prepared according to the present  
10 invention using  $\gamma$ -phase SVO as a starting material in  
combination with copper(II) oxide. In particular, a  
1.80 gram sample of  $\text{Ag}_{1.2}\text{V}_3\text{O}_{8.1}$  was combined with a 0.10  
gram sample of  $\text{CuO}$ , and heated to about  $450^\circ\text{C}$ . under a  
flowing air atmosphere for about 16 hours. The sample  
15 was then cooled, mixed and reheated under a flowing air  
atmosphere at about  $500^\circ\text{C}$ . for about 24 hours. At this  
point, the material was cooled and analyzed by BET  
surface area measurements. The material displayed a BET  
surface area of  $0.31 \text{ m}^2/\text{g}$ .

20

## Comparative Example 3

As a comparison to the product of Example 3, CSV0  
was prepared via the prior art decomposition method  
25 using  $\text{V}_2\text{O}_5$ ,  $\text{Cu}(\text{NO}_3)_2$  and  $\text{AgNO}_3$ . In particular, a 1.36  
gram sample of  $\text{V}_2\text{O}_5$  was combined with a 0.99 gram sample  
of  $\text{AgNO}_3$  and a 0.34 gram sample of  $\text{Cu}(\text{NO}_3)_2 \cdot 2.5\text{H}_2\text{O}$ , and  
heated to about  $400^\circ\text{C}$ . under a flowing air atmosphere  
for about 16 hours. The sample was then cooled, mixed  
30 and reheated under a flowing air atmosphere at about  
 $500^\circ\text{C}$ . for about 44 hours. At this point, the product  
material was cooled and analyzed by BET surface area  
measurement. The material displayed a BET surface area  
of  $0.45 \text{ m}^2/\text{g}$ , which is significantly higher than the  
35 specific surface area of the CSV0 material prepared in  
Example 3. Thus, in addition to the toxic implications  
of released  $\text{NO}_x$  gas, the preparation of CSV0 by the

5 prior art method provides a material with a higher specific surface area than the new preparation technique.

10 The above detailed description and examples are intended for the purpose of illustrating the invention, and are not to be construed as limiting. For example, starting materials other than silver oxide and silver carbonate are reacted with  $\gamma$ -phase silver vanadium oxide to form  $\epsilon$ -phase silver vanadium compounds. The list includes: silver lactate ( $\text{AgC}_3\text{H}_5\text{O}_3$ ,  $T_m$  120°C.), silver  
15 triflate ( $\text{AgCF}_3\text{SO}_3$ ,  $T_m$  286°C.), silver pentafluoropropionate ( $\text{AgC}_3\text{F}_5\text{O}_2$ ,  $T_m$  242°C.), silver laurate ( $\text{AgC}_{12}\text{H}_{23}\text{O}_2$ ,  $T_m$  212°C.), silver myristate ( $\text{AgC}_{14}\text{H}_{27}\text{O}_2$ ,  $T_m$  211°C.), silver palmitate ( $\text{AgC}_{16}\text{H}_{31}\text{O}_2$ ,  $T_m$  209°C.), silver stearate ( $\text{AgC}_{18}\text{H}_{35}\text{O}_2$ ,  $T_m$  205°C.), silver  
20 vanadate ( $\text{AgVO}_3$ ,  $T_m$  465°C.), copper oxide ( $\text{CuO}$ ,  $T_m$  1,446°C.), copper carbonate ( $\text{Cu}_2\text{CO}_3$ ), manganese carbonate ( $\text{MnCO}_3$ ), manganese oxide ( $\text{MnO}$ ,  $T_m$  1,650°C.), magnesium carbonate ( $\text{MgCO}_3$ ,  $T_d$  350°C.), magnesium oxide ( $\text{MgO}$ ,  $T_m$  2,826°C.), and combinations and mixtures thereof.

25 While the starting materials are described as being heated to a preferred temperature of about 500°C., it is contemplated by the scope of the present invention that suitable heating temperatures range from about 300°C. to about 550°C., depending on the specific starting  
30 materials. Also, heating times for both the first and second heating step range from about 5 hours to about 30 hours. Longer heating times are required for lower heating temperatures. Further, while the present invention has been described in the examples as  
35 requiring two heating events with an ambient mixing in

5 between, that is not necessarily imperative. Some  
synthesis protocols according to the present invention  
may require one heating step with periodic mixing, or  
multiple heating events with periodic ambient mixing.

10 The product mixed metal oxides according to the  
present invention include:  $\epsilon$ -phase SVO ( $\text{Ag}_2\text{V}_4\text{O}_{11}$ ), CSV0  
( $\text{Cu}_{0.2}\text{Ag}_{0.8}\text{V}_2\text{O}_{5.6}$ ), MnSVO ( $\text{Mn}_{0.2}\text{Ag}_{0.8}\text{V}_2\text{O}_{5.8}$ ), and MgSVO  
( $\text{Mg}_{0.2}\text{Ag}_{0.8}\text{V}_2\text{O}_{5.6}$ ). The use of the above mixed metal  
oxides as a cathode active material provides an  
15 electrochemical cell that possesses sufficient energy  
density and discharge capacity required to meet the  
vigorous requirements of implantable medical devices.  
These types of cells comprise an anode of a metal  
selected from Groups IA, IIA and IIIB of the Periodic  
Table of the Elements. Such anode active materials  
20 include lithium, sodium, potassium, etc., and their  
alloys and intermetallic compounds including, for  
example, Li-Mg, Li-Si, Li-Al, Li-B and Li-Si-B alloys  
and intermetallic compounds. The preferred anode  
comprises lithium. An alternate anode comprises a  
25 lithium alloy such as a lithium-aluminum alloy. The  
greater the amount of aluminum present by weight in the  
alloy, however, the lower the energy density of the  
cell.

30 The form of the anode may vary, but preferably the  
anode is a thin metal sheet or foil of the anode metal,  
pressed or rolled on a metallic anode current collector,  
i.e., preferably comprising titanium, titanium alloy or  
nickel, to form an anode component. Copper, tungsten  
and tantalum are also suitable materials for the anode  
35 current collector. In the exemplary cell of the present

5 invention, the anode component has an extended tab or  
lead of the same material as the anode current  
collector, i.e., preferably nickel or titanium,  
integrally formed therewith such as by welding and  
10 contacted by a weld to a cell case of conductive metal  
in a case-negative electrical configuration.  
Alternatively, the anode may be formed in some other  
geometry, such as a bobbin shape, cylinder or pellet to  
allow an alternate low surface cell design.

Before the previously described  $\epsilon$ -phase active  
15 materials are fabrication into a cathode electrode for  
incorporation into an electrochemical cell, they are  
preferably mixed with a binder material, such as a  
powdered fluoro-polymer, more preferably powdered  
polytetrafluoro-ethylene or powdered polyvinylidene  
20 fluoride, present at about 1 to about 5 weight percent  
of the cathode mixture. Further, up to about 10 weight  
percent of a conductive diluent is preferably added to  
the cathode mixture to improve conductivity. Suitable  
materials for this purpose include acetylene black,  
25 carbon black and/or graphite or a metallic powder such  
as of nickel, aluminum, titanium and stainless steel.  
The preferred cathode active mixture thus includes a  
powdered fluoro-polymer binder present at about 3 weight  
percent, a conductive diluent present at about 3 weight  
30 percent and about 94 weight percent of the cathode  
active material. For example, depending on the  
application of the electrochemical cell, the range of  
cathode compositions is from about 99% to about 80%, by  
weight,  $\epsilon$ -phase silver vanadium oxide mixed with carbon  
35 graphite and PTFE.

5 Cathode components for incorporation into an  
electrochemical cell according to the present invention  
may be prepared by rolling, spreading or pressing the  
cathode active materials onto a suitable current  
collector selected from the group consisting of  
10 stainless steel, titanium, tantalum, platinum, gold,  
aluminum, cobalt-nickel alloys, nickel-containing  
alloys, highly alloyed ferritic stainless steel  
containing molybdenum and chromium, and nickel-,  
chromium- and molybdenum-containing alloys. The  
15 preferred current collector material is titanium and,  
most preferably, the titanium cathode current collector  
has a thin layer of graphite/carbon material, iridium,  
iridium oxide or platinum applied thereto. Cathodes  
prepared as described above may be in the form of one or  
20 more plates operatively associated with at least one or  
more plates of anode material, or in the form of a strip  
wound with a corresponding strip of anode material in a  
structure similar to a "jellyroll".

In order to prevent internal short circuit  
25 conditions, the cathode is separated from the Group IA,  
IIA or IIIB anode by a suitable separator material. The  
separator is of electrically insulative material, and  
the separator material also is chemically unreactive  
with the anode and cathode active materials and both  
30 chemically unreactive with and insoluble in the  
electrolyte. In addition, the separator material has a  
degree of porosity sufficient to allow flow there  
through of the electrolyte during the electrochemical  
reaction of the cell. Illustrative separator materials  
35 include fabrics woven from fluoropolymeric fibers

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5 including polyvinylidene fluoride,  
polyethylenetetrafluoroethylene, and  
polyethylenechlorotrifluoroethylene used either alone or  
laminated with a fluoropolymeric microporous film,  
non-woven glass, polypropylene, polyethylene, glass  
10 fiber materials, ceramics, a polytetrafluoroethylene  
membrane commercially available under the designation  
ZITEX (Chemplast Inc.), a polypropylene membrane  
commercially available under the designation CELGARD  
(Celanese Plastic Company, Inc.) and a membrane  
15 commercially available under the designation DEXIGLAS  
(C.H. Dexter, Div., Dexter Corp.).

The electrochemical cell of the present invention  
further includes a nonaqueous, ionically conductive  
electrolyte which serves as a medium for migration of  
20 ions between the anode and the cathode electrodes during  
the electrochemical reactions of the cell. The  
electrochemical reaction at the electrodes involves  
conversion of ions in atomic or molecular forms which  
migrate from the anode to the cathode. Thus, nonaqueous  
25 electrolytes suitable for the present invention are  
substantially inert to the anode and cathode materials,  
and they exhibit those physical properties necessary for  
ionic transport, namely, low viscosity, low surface  
tension and wettability.

30 A suitable electrolyte has an inorganic, ionically  
conductive salt dissolved in a nonaqueous solvent, and  
more preferably, the electrolyte includes an ionizable  
alkali metal salt dissolved in a mixture of aprotic  
organic solvents comprising a low viscosity solvent and  
35 a high permittivity solvent. The inorganic, ionically

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5     conductive salt serves as the vehicle for migration of  
the anode ions to intercalate or react with the cathode  
active material. Preferably, the ion forming alkali  
metal salt is similar to the alkali metal comprising the  
anode.

10         In the case of an anode comprising lithium, the  
alkali metal salt of the electrolyte is a lithium based  
salt. Known lithium salts that are useful as a vehicle  
for transport of alkali metal ions from the anode to the  
cathode include  $\text{LiPF}_6$ ,  $\text{LiBF}_4$ ,  $\text{LiAsF}_6$ ,  $\text{LiSbF}_6$ ,  $\text{LiClO}_4$ ,  
15      $\text{LiO}_2$ ,  $\text{LiAlCl}_4$ ,  $\text{LiGaCl}_4$ ,  $\text{LiC}(\text{SO}_2\text{CF}_3)_3$ ,  $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ,  $\text{LiSCN}$ ,  
 $\text{LiO}_3\text{SCF}_3$ ,  $\text{LiC}_6\text{F}_5\text{SO}_3$ ,  $\text{LiO}_2\text{CCF}_3$ ,  $\text{LiSO}_6\text{F}$ ,  $\text{LiB}(\text{C}_6\text{H}_5)_4$ ,  $\text{LiCF}_3\text{SO}_3$ ,  
and mixtures thereof.

Low viscosity solvents useful with the present  
invention include esters, linear and cyclic ethers and  
20     dialkyl carbonates such as tetrahydrofuran (THF), methyl  
acetate (MA), diglyme, triglyme, tetraglyme, dimethyl  
carbonate (DMC), 1,2-dimethoxyethane (DME), 1,2-  
diethoxyethane (DEE), 1-ethoxy,2-methoxyethane (EME),  
ethyl methyl carbonate, methyl propyl carbonate, ethyl  
25     propyl carbonate, diethyl carbonate, dipropyl carbonate,  
and mixtures thereof. Suitable high permittivity  
solvents include cyclic carbonates, cyclic esters and  
cyclic amides such as propylene carbonate (PC), ethylene  
carbonate (EC), butylene carbonate (BC), acetonitrile,  
30     dimethyl sulfoxide, dimethyl, formamide, dimethyl  
acetamide,  $\gamma$ -valerolactone,  $\gamma$ -butyrolactone (GBL),  
N-methyl-pyrrolidinone (NMP), and mixtures thereof. In  
the present invention, the preferred anode is lithium  
metal and the preferred electrolyte is 0.8M to 1.5M  
35      $\text{LiAsF}_6$  or  $\text{LiPF}_6$  dissolved in a 50:50 mixture, by volume,



5 of propylene carbonate as the preferred high  
permittivity solvent and 1,2-dimethoxyethane as the  
preferred low viscosity solvent.

The preferred form of a primary alkali metal/solid  
cathode electrochemical cell is a case-negative design  
10 wherein the anode is in contact with a conductive metal  
casing and the cathode contacted to a current collector  
is the positive terminal. The cathode current collector  
is in contact with a positive terminal pin via a lead of  
the same material as the current collector. The lead is  
15 welded to both the current collector and the positive  
terminal pin for electrical contact.

A preferred material for the casing is titanium  
although stainless steel, mild steel, nickel-plated mild  
steel and aluminum are also suitable. The casing header  
20 comprises a metallic lid having an opening to  
accommodate the glass-to-metal seal/terminal pin  
feedthrough for the cathode electrode. The anode  
electrode is preferably connected to the case or the  
lid. An additional opening is provided for electrolyte  
25 filling. The casing header comprises elements having  
compatibility with the other components of the  
electrochemical cell and is resistant to corrosion. The  
cell is thereafter filled with the electrolyte solution  
described hereinabove and hermetically sealed such as by  
30 close-welding a titanium plug over the fill hole, but  
not limited thereto. The cell of the present invention  
can also be constructed in a case-positive design.

It is appreciated that various modifications to the  
inventive concepts described herein may be apparent to  
35 those of ordinary skill in the art without departing

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- 5 from the spirit and scope of the present invention as defined by the appended claims.

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